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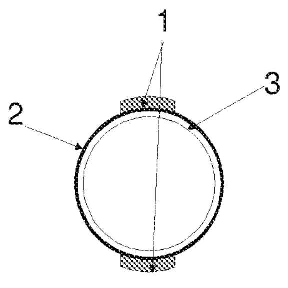
(54) **Title:** FLOW SENSOR BASED ON A PIEZOELECTRIC POLYMER



(57) Abstract: The present invention is related to a device through which a liquid or gas fluid flows, allowing the measurement of the respective flow. The device of tubular form is conceived in single part, manufactured from a piezoelectric polymer such as PVDF (2), in which one or more electrodes are placed in its interior (3) and one or more electrodes are placed in its exterior (1). When one of the exterior electrodes is excited by electric voltage, whose frequency is placed in the scope of tens or hundreds of megahertz, the area of the pipe that is in contact with it oscillates, producing an ultrasound with the same frequency. Depending on the readout technique used, the areas of the pipe below the other electrodes (in the case that there is more than one electrode) also work as ultrasound transducers, receiving the signal produced by the first one. There are basically two readout methods of flow sensors based on ultrasounds: the Doppler Effect and the time of transit. In any of these methods, the frequency or phase shifts between the emitted and the received signals are used to calculate the speed of the liquid or gas passing through the pipe. The flow is then calculated by multiplying the speed of the fluid by the area of the section of the pipe.

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DESCRIPTION

"FLOW SENSOR BASED ON A PIEZOELECTRIC POLYMER"

Scope of the invention

The present invention relates to the detention of liquid or gas passing through a pipe or tube. This amount or flow is calculated through the introduction of an ultrasound wave by a transducer working as emitter, and the respective reception of the signal by the same or other transducers placed in its neighborhood. The sensor is composed by a single part manufactured from a polymer with piezoelectric features.

Background of the invention

In order to detect a flow that crosses a pipe, a flow meter is used whose working principle can be based on ultrasounds. In this case, acoustic waves with frequencies superior to 20 kHz are used. Depending on the geometry, the transducers that emit and receive the ultrasounds can be in direct contact with the fluid to be measured or can be isolated from this by a material that makes the acoustic coupling between the transducer and the fluid.

The main advantages of the use of ultrasound flow sensors are the following:

- There is no blockage for the circulation of the fluid. Therefore, there are no pressure drop zones in the interior of the pipe.
- It does not have any mobile parts, therefore it does not require maintenance.
- It can be used to measure corrosive or semi-liquid fluids such as mud or cement.

Basically, there are two methods for designing ultrasonic flow sensors: those based on the Doppler Effect and those based on the time of transit of ultrasounds.

The Doppler Effect states that sound wave frequencies depend on the emitter or receptor movement in relation to the propagation medium. In order to use this effect in the measurement of liquid flows in a pipe, a transducer emits ultrasounds through the flow at a frequency of 500 kHz. Some particles or air bubbles suspended in the liquid fluid reflect the ultrasounds back to a second transducer that will receive them. The same transducer can emit and receive the sound waves, being in this case necessary that these are pulsed, that is, a pulse is sent, the echo is awaited and only then a second pulse is sent and thus successively. The movement of those particles or air bubbles modifies the frequency of the beam reflected according to the Doppler Effect. The frequency shift is proportional to the speed of those particles and consequently to the speed of the liquid that crosses the pipe. The basic equations that rule this phenomenon are the following:

$$\Delta f = 2 f_T \sin\theta \frac{v}{c} \qquad (1)$$

wherein Δf is the Doppler frequency shift, f_T is the operation frequency of the sound wave emitter, θ is the angle in which the ultrasounds enter the flow, v is the flow and c is the propagation speed of the sound in the fluid when it is idle. According to Snell's law:

$$\frac{\sin\theta_T}{c_T} = \frac{\sin\theta}{c} \qquad (2)$$

wherein θ_T is the angle between the direction of ultrasound propagation and flow direction and c_T is the propagation of the ultrasound in the material that constitutes the emitter.

From equations (1) and (2) it is obtained:

$$v = \frac{\Delta f}{f_T} \frac{c_T}{\sin \theta_T} = K\Delta f, \qquad (3)$$

wherein:

$$K = \frac{c_T}{f_T \sin \theta_T}$$

Equation (3) evidences that the fluid speed is proportional to the Doppler frequency shift. By knowing its speed, the flow can be calculated by multiplying it by the area of the pipe. The main inconvenience in the use of the Doppler Effect in measuring flows is that it only works properly in the presence of suspended particles in the fluid.

The flow meters based on the time of transit, as assumed by the name, measure the difference between the time that ultrasounds take to cover a certain distance, both in the flow direction and in the opposite direction. The time of transit in the direction of the flow can be calculated from:

$$T_1 = \frac{L}{c + V \cos \theta}, \qquad (4)$$

wherein L is the distance between the transducers and θ is the angle between the flow direction and the line that joins both transducers. Likewise, the time of transit in the opposite flow can be calculated from:

$$T_2 = \frac{L}{c - V \cos \theta}. \qquad (5)$$

Equations (4) and (5) can be simultaneously solved in order to c and v, the propagation of the sound in the fluid and the fluid speed being attained:

$$c = \frac{L(T_1 + T_2)}{2T_1T_2} \tag{6}$$

$$v = \frac{L(T_2 - T_1)}{2T_1T_2 \cos\theta} \tag{7}$$

Once again, based on the fluid speed, the flow can be calculated by multiplying it by the area of the pipe.

There are many applications and several methods and geometries that can be used to measure the volumetric flow of fluids. One of these methods uses the Doppler Effect, using the echoes produced in particles or air bubbles suspended in a liquid fluid. Usually one or two piezoelectric transducers (piezocrystals or piezoceramics) are coupled in some way to the pipe in which the fluid to be measured flows. Some of the applications using this effect are presented:

US2005/0209793 describes a flow sensor based on the Doppler Effect in which only one ultrasound transducer is used connected to the pipe. An algorithm is also described for the correction of the quantization error.

JP2004108946 describes a flow sensor based on the Doppler Effect that additionally measures the real propagation of the sound in the liquid in question. In this case, four ultrasonic transducers are used: one for the measurement of the Doppler shift and three for the measurement of sound within the liquid circulating in the pipe.

JP2005241437 describes a flow sensor based on the Doppler Effect in which a technique is used to reduce the influence of the acoustic noise resultant of the reflection between the exterior face of the pipe and the transducer and the reverberation emitted by the transducer itself. An ultrasound transducer assembled in the exterior of the pipe is used.

In US2005011279 and US2005245827 a flow sensor based on the Doppler Effect and a readout system thereof are described. In this case, an ultrasound transducer placed in the exterior of the pipe is used.

WO2005083371 describes a flow sensor based on the Doppler Effect using two ultrasound transducers: one in order to emit the pulses and another to receive the echoes produced. The transducers are placed in the exterior of the pipe.

Another method for measuring the flow trough ultrasonic waves consists of measuring the time of transit of the ultrasound when traveling though the fluid. In this case, piezoelectric transducers (piezocrystals or piezoceramics) are also usually used, being somehow coupled to a pipe in which the flow to be measured circulates. Some documents using this effect are hereinafter presented.

EP1211488A2 describes a flow sensor based on the time of transit and uses two ultrasound transducers connected to a U-shape pipe. The two transducers work alternately as ultrasound emitter/receptor.

GB2300265 describes a flow sensor based on the time of transit and uses four ultrasound transducers and a temperature sensor connected to the pipe. From the ultrasound transducers, two of them determine the time of transit, the third being conceived to measure the sound speed in the fluid and the fourth to measure the thickness of the pipe walls.

GB2400439 describes a flow sensor based on the time of transit and uses two piezoelectric transducers in a ring form placed inside two cuts within the pipe.

WO0003206 describes the use of several ultrasound transducers (at least three) connected to the pipe, allowing measuring flow rates and speeds.

From the known applications using either of the presented methods, only few use piezoelectric polymers (PVDF, for example) instead of the piezocrystals or piezoceramics.

GB2203546 describes the use of a layer from a quarter of the wave length and piezoelectric ceramics to form an oscillator and thus to emit ultrasound.

The above-mentioned invention in GB2220485 uses the vibrations produced by the fluid movement to generate electric voltage in a PVDF film.

The invention referred to in WO0169182 uses a film glued in the exterior of the pipe. The measurement is done by using the electric voltage obtained by the vibration of the movement of the fluid.

Of the known and previously presented state-of-the-art, no technology refers the use of a single pipe made in a piezoelectric polymer similar to the invention now disclosed, which presents the advantages of being a simple, robust and compact system, whose production process presents very few steps, allowing pipe diameters from several micrometers millimeter to tens of centimeters.

Brief description of the figures

Figure 1 shows a drawing of the sensor based on the Doppler effect with a single transducer; pipe manufactured from a piezoelectric polymer (2); electrode in the interior of pipe (3); exterior electrode (1); sound waves (5); direction (4); suspended particles in the fluid (6).

Figure 2 shows a drawing of the sensor based on the Doppler effect comprising two exterior electrodes (1).

Figure 3 shows a drawing of the sensor based on the time of transit using two exterior electrodes (1).

Figure 4 shows a drawing of the sensor based on the time of transit using three exterior electrodes (1).

Figure 5 shows a drawing of the sensor based on the time of transit using four exterior electrodes (1).

Figure 6 is a cross sectional view of the device in figure 4.

Detailed description of the invention

In any of the two previously presented types of flow sensors, the pipe is manufactured from a piezoelectric polymer (2), where one or more electrodes of conducting material (aluminum, for example) are placed in its interior (3) and one or more electrodes of conducting material are placed in its exterior (1) forming together with the piezoelectric polymer the ultrasound transducers.

The pipe that will derive the flow sensor might be obtained by conventional methods, such as extrusion, injection or another method for polymer processing in tubular form. Once the pipe is obtained, it is subjected to the application of an electric field of about tens of megavolts per meter, being this process known as electric poling of the polymeric material. After the poling step, the metallic contacts are deposited in the polymer surface. The exterior electrodes work as electric contacts for the ultrasound transducers which can also be transmitters or receivers of the sound waves (5).

The sensor in figure 1 is based on the Doppler Effect and has only one transducer. This transducer operates as emitter and receiver of the sound waves. The transducer sends sound waves that after striking against any suspended particle in the fluid are reflected by these particles back to the transducer. Once the sound waves are sent, the transducer waits for the reception of its echo, after which a second signal is emitted and so on.

In the sensor of figure 2, the transducer can be continuously sending the ultrasound signal, as a second transducer will receive the waves reflected by the particles.

In both sensors in figures 1 and 2, the particle motion in the fluid alters the frequency of the reflected beam according to the Doppler Effect. The frequency shift is proportional to the speed of these particles and consequently, to the speed of the liquid flowing within the pipe.

In the sensor based on the time of transit in figure 3, both transducers can work as emitters and receivers of the ultrasonic waves. These waves are emitted by the lower transducer in the fluid direction (4) and (5) and depending on the fluid speed, they take more or less time to achieve the upper transducer. The upper transducer equally emits a sound signal, which in the case of this figure 3 is in the direction opposite to the one of the fluid and will be received by the lower transducer. Thus, depending on the time of transit of the ultrasonic waves in the fluid, the sound speed and the fluid are determined.

The sensor of figure 4 uses a transducer in order to emit the ultrasonic waves and two transducers to receive them. Depending on the time they take to arrive to the receiver transducers, the sound speed and the fluid are determined.

The sensor of figure 5 uses four emitter and receiver transducers of ultrasonic waves. Its behavior is similar to the one of the sensor in figure 3. The control of the emission and reception of the ultrasonic waves can be made by using two transducers as emitters and other two as receivers, always the same, or alternating the emitter and receiver functions between the four transducers. In the case of figure 5, the upper and lower transducers on the left hand are operating as emitters and the other two as receivers.

These different examples of sensors provide different situations of flow measurement: the sensors in figures 1 and 2 use the Doppler Effect and need that the fluids contain suspended particles. Its operating principle is identical, however, the sensor of figure 1 needs more complex readout electronics, once the ultrasonic transducer works alternately as emitter and receiver. The sensors in figures 3, 4 and 5 use the time of transit method and operate in homogeneous fluids. In the case of figures 3 and 5, as ultrasound transducers operate alternately as emitter or receiver, the readout electronics is more complex. The sensor in figure 4 operates in a similar way, but the electronics is simpler, once there's no emitter/ receiver commutation of the ultrasonic transducers. The sensor in figure 5, despite having the most complex configuration, has the advantage of showing a higher resolution in the flow readout.

All these sensors are directly based on the present invention, they constitute non limitative examples of sensor application, which can be subject to modifications and variations carried out by a skilled in the art, the modifications being yet enclosed in the scope of the invention, as defined by the following claims.

CLAIMS

1. Flow sensor based on ultrasound, comprising:
   - a pipe or tube (2) manufactured from a polymer with piezoelectric characteristics;
   - one or more conducting electrodes (3) in its interior and one or more electrodes in its exterior (1), forming, together with the piezoelectric polymer, one or more ultrasound transducers.

2. Flow sensor according to claim 1, characterized in that the electrodes (1, 3) can be metallic, conducting polymers or of some material leading the electric current.

3. Flow sensor according to claim 1, comprising a conductive electrode in its interior (3) and a conductive electrode in its exterior (1), forming together with the piezoelectric polymer an ultrasound transducer, where the method based on the Doppler effect is used in order to measure the flow.

4. Flow sensor according to claim 1, comprising a conductive electrode in its interior (3) and two conductive electrodes (1) in its exterior, forming together with the piezoelectric polymer two ultrasound transducers, wherein the method based on the Doppler effect is used to measure the flow.

5. Flow sensor according to claim 4 characterized in that each transducer operates alternately as emitter or receiver, wherein the method based on the time of

transit to measure the flow passing though the pipe (2) is used.

6. Flow sensor according to claim 1, comprising a conducting electrode in its interior (3) and three conducting electrodes (1) in its exterior, forming together with the piezoelectric polymer three ultrasound transducers.

7. Flow sensor according to claim 6, characterized in that a transducer operates as emitter and two transducers operate as receivers, wherein the method based on the time of transit to calculate the flow that passes though the pipe (2) is used.

8. Flow Sensor based on ultrasound according to claim 1, comprising a conducting electrode in its interior (3) and four or more electrodes (1) in its exterior, forming together with the piezoelectric polymer four or more ultrasound transducers.

9. Flow sensor according to claim 8, characterized in that the transducers can operate alternately as emitters and receivers of ultrasounds, wherein either the method based on the Doppler effect or the method based on the time of transit can be used to calculate the flow that passes though the pipe (2).

10. Process for the manufacture of a flow sensor according to the preceding claims, comprising the following steps:
- extrusion, injection or another method for processing polymeric material in a pipe form;

- application of an electric field for the polarization of the polymer;
- deposition of the electrodes.

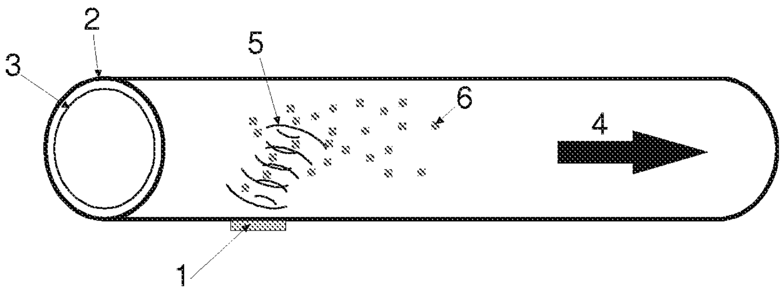

Figure 1

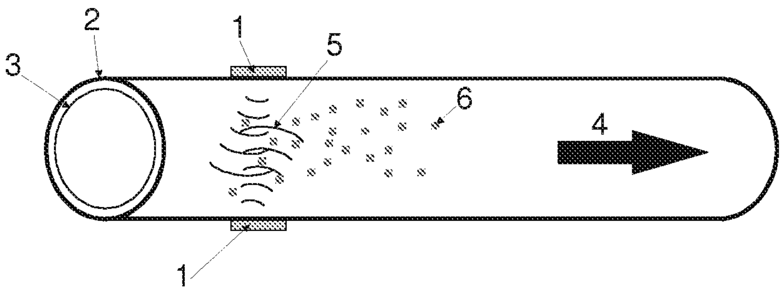

Figure 2

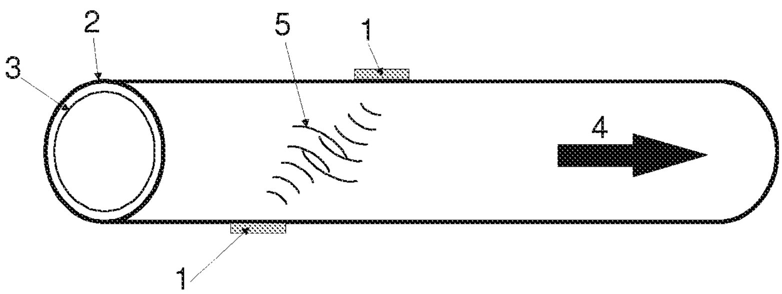

Figure 3

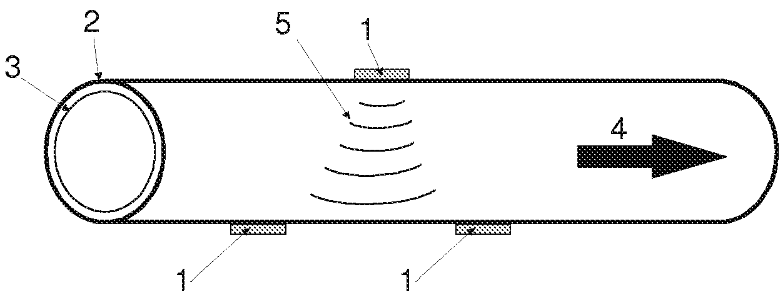

Figure 4

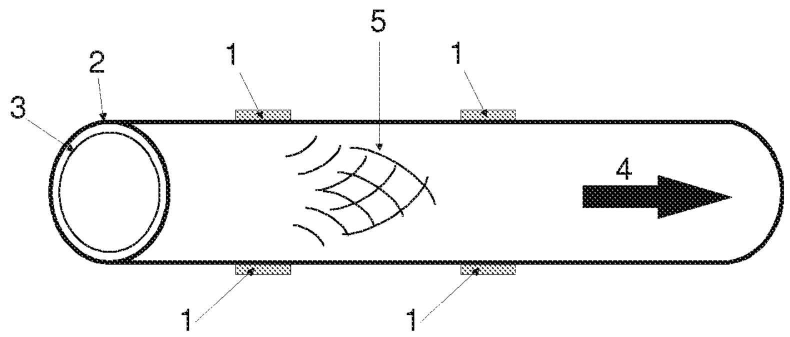

Figure 5

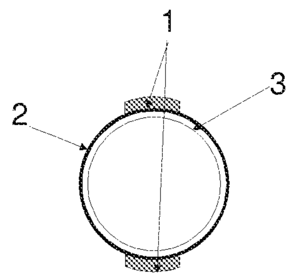

Figure 6